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DEPENDENCE OF THE CRACK DEPTH ON GLASS CUTTING SPEED

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The relationship between the depth of the median crack emerging in the course of glass cutting beneath a roll cutter, the work done on producing the crack, and the speed of inscribing the cutting line is studied. It is established that the maximum value of the work done on producing the crack corresponds to the optimum cutting speed.

The glass cutting process consists of two operations: inscribing the cutting line on the glass surface using a hard-alloy roller, and glass fracture along this cutting line. In the course of cutting, a system of cracks emerges beneath the roll cutter [1], and the quality of the resulting glass edge depends on the type and size of these cracks. A strong high-quality edge is accomplished by fracturing glass with a median crack of sufficient depth (0.3–0.5 mm) [2]. Therefore, the cutting parameters (the pressure applied to the roll cutter, its sharpening angle, the speed of cutting, etc.) are of special importance for the cutting process, and the emergence of a median crack of the required size depends on adherence to these parameters. The site of the crack origin in glass beneath a roll cutter and the crack propagation stages were established earlier [3].

The purpose of the present paper was to determine the dependence of the depth of the crack in glass on the rate of inscribing the cutting line, and to identify the optimum cutting speed.

Several authors observed the effect of the cutting speed on the depth of the median crack in glass; however, no

unique opinion on this issue exists as yet. For instance, according to Peter's data [4], with an increase in the rate of inscribing cutting line, the depth of the median crack decreases, and according to Insolio [5], with an increasing cutting rate using the diamond cutter, the depth of the median crack grows. According to the study by Litvinov [6], the fracture force and, therefore, the crack depth do not depend on the rate of inscribing the cutting line.

Under the effect of a roll cutter whose force is sufficient for cracking, a typical stress distribution situation emerges in the glass. In Fig. 1 one can see two compression zones and three tension zones. Since the tensile strength of glass is about one-hundredth of the compressive strength, the fracture originates in the tension zones along the maximum stress line. There are three maximum stress lines: one vertical and two lateral ones. Indeed, three cracks are formed in glass cutting: the median crack directed deep into the glass and two lateral cracks (Fig. 2). The present paper considers only the median crack.

The crack depth was measured using a MBS-1 microscope at $\times 56$ magnification by viewing the cracked samples from the end. The measurement precision was ± 0.01 mm. The sample size was 25×50 mm. The glass thickness was 5 mm. The cutting line was inscribed on the glass surface by a VK-3 hard-alloy roll cutter with a sharpening angle of 130° and a transverse cutting beam which allows for smooth variation of the cutting speed from 0.4 to 4.7 m/sec.



Fig. 1. Stress distribution in glass during crack formation ($\times 40$).



Fig. 2. Cracks forming in glass beneath a roll cutter ($\times 25$).

The current load on the beam drive was registered by an M 502 mirror standard ammeter (class 0.10 with ± 0.04 A precision of registration in the course of inscribing the cutting line (the working stroke) and without inscribing it (the idle stroke). The difference in the current loads was attributed to the work on producing a crack in the glass:

$$A = U\Delta I t,$$

where A is the work done on producing a crack, J; U is the voltage on the drive of the transverse cutting beam, V; ΔI is the current difference (between the working and idle strokes), A; t is the time of inscribing the cutting line; $t = B/v$ (B is the glass band width, or the cutting line length, mm; v is the cutting speed, m/sec).

In the course of the experiment, the cutting speed varied, while the other technological parameters remained constant. The experiments included cutting both cold (25°C) and hot (620°C) glass. The cold glass was cut with and without propping liquid, under various loads applied to the roll cutter.

The curves for the depth of the median crack resulting from inscribing the cutting line as a function of the cutting speed (Fig. 3) were plotted based on the experimental results. It can be seen that the shape of the curves persists, and only the crack depth varies. All curves have two maxima, i.e., the crack depth first grows and attains the maximum value and then, with a further increase in the cutting speed, it decreases. When propping liquid is used (Fig. 3a, curve 2), this decrease is only 4%, and without propping agent, the crack depth decreased to one-sixth. This is due to the effect of the propping liquid which facilitates the growth of the median crack into the glass depth and impedes the formation of the lateral cracks. Next, having attained the minimum value, the crack depth increases and attains the second maximum.

Figure 4 shows the cutting speed dependence of the work done on producing a crack. The experiments indicated that the relationship between the median crack depth and the cutting speed at 25°C and 620°C is of a similar nature. In the present paper, the dependence of the work done on producing a crack versus the cutting speed is given for 620°C, since the most complete data were obtained in studying the glass cutting process in the viscoelastic state.

It can be seen in Fig. 4, that the relationship between the work done on producing the crack and the cutting speed is of the same nature as the dependence of the crack depth on the cutting speed (Fig. 3). Moreover, the maximum values of the work done on the crack and of the crack depth relate to approximately equal cutting rate values.

As the result of the experiment, it was found that the cutting rates corresponding to the maximum values of the work done on the crack can be regarded as the most appropriate for efficient glass cutting. The best quality of the glass edge can be achieved in these conditions. The cutting temperature in this case was 620°C, and the optimum cutting speeds were 0.8–1.1 and 2.5–3.3 m/sec. However, in the case of cutting hot glass, the second maximum range is preferable,

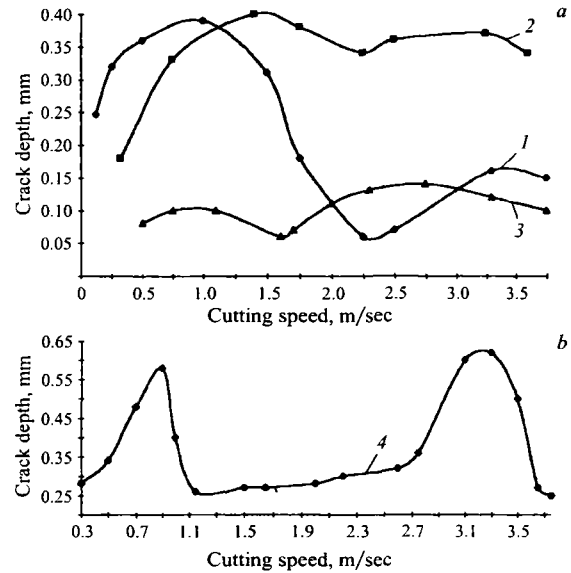


Fig. 3. Dependence of the crack depth on the cutting speed at the glass temperature of 15°C (a) and 620 ± 5°C (b): 1) without propping liquid, load on the cutter 50 N; 2) with propping liquid, load on the cutter 50 N; 3) with propping liquid, load on the cutter 30 N; 4) without propping liquid, load on the cutter 70 N.

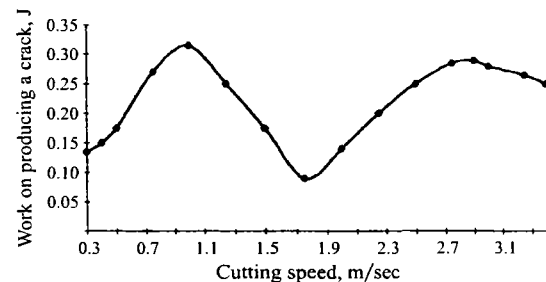


Fig. 4. The work done on producing a crack versus cutting speed.

since in that case the relaxation processes are suppressed, which has been practically corroborated during the experiment and is observed on the site where the maximum compression used to exist. Cutting was performed at a temperature of 620°C and a cutting rate of 3.0 m/sec.

To elucidate the origin of two maxima on the curves let us take into account the laws of crack formation in the glass.

There is a time lag between the onset of crack developing and the moment of roll indentation into the glass. This time lag is necessary for redistribution of stresses in the glass. The stresses change the sign: maximum compression turns into maximum strain. The time of crack formation depends on the load on the roller, and for a load of 50 N this interval is 8 msec [3]. During this interval, the roller travels a distance of 9 mm at a cutting rate of 1.1 m/sec (the speed corresponding to the first maximum), and with a speed of 3.3 m/sec (the second maximum), the roller covers a distance of 27 mm.

The roll cutter moving over the glass surface is the wave initiation center. Tensile stresses on the glass surface are observed at the wave crests, and compression stresses are observed in the wave troughs.

When the crack initiation point coincides with a wave crest, the crack obtains an additional impetus for its growth and becomes longer; and when this point occurs in a wave trough, the crack is delayed. The first wave crest from the roller generates the maximum impetus, and the effect of the other crests monotonically declines. Therefore, the first maximum in the cold glass curve is 2.5 times higher than the second one.

The first maximum in viscoelastic (hot) glass is lower than the second maximum, since the relaxation effects which rapidly reduce the stresses produced by the roller play a crucial role in this case.

At a low cutting speed (1 m/sec), the duration of the cutter impact on the glass is comparable to the stress relaxation time, and during the stress redistribution (0.008 sec), 30–40% of the stresses have time to relax. With a cutting speed of 3.3 m/sec, the duration of the cutter impact on glass decreases 3.4 times and becomes significantly less than the stress relaxation duration; accordingly, 95% stresses caused by the cutter remain in the glass after the relaxation and the glass becomes brittle; therefore, the second maximum becomes higher than the first one. In cutting hot glass, the relaxation effects have to be compensated by an increased load on the cutter.

The use of kerosene as the propping liquid in cutting elastic (cold) glass significantly alters the crack-forming dynamics. Two powerful stress zones arise at both sides of the

crack and stretch it in opposite directions. The crack originates immediately after the cutter passes. The absence of a delay in the crack formation makes the maxima smoother.

Thus, within the range of 0.4–4.7 m/sec there are two optimum glass-cutting speeds which lead to maximum depth of the median crack in the glass (0.8–1.1 and 2.5–3.3 m/sec) and result in a high-quality strong edge of the cut glass. The use of the propping liquid is superimposed on the glass fracture process: the liquid props the crack, modifies its stressed state, and makes the maxima smoother. The operation of glass manufacturers within the critical range of the cutting speed (1.1–2.5 m/sec) is admissible but requires reliable and ample feeding of the propping liquid.

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